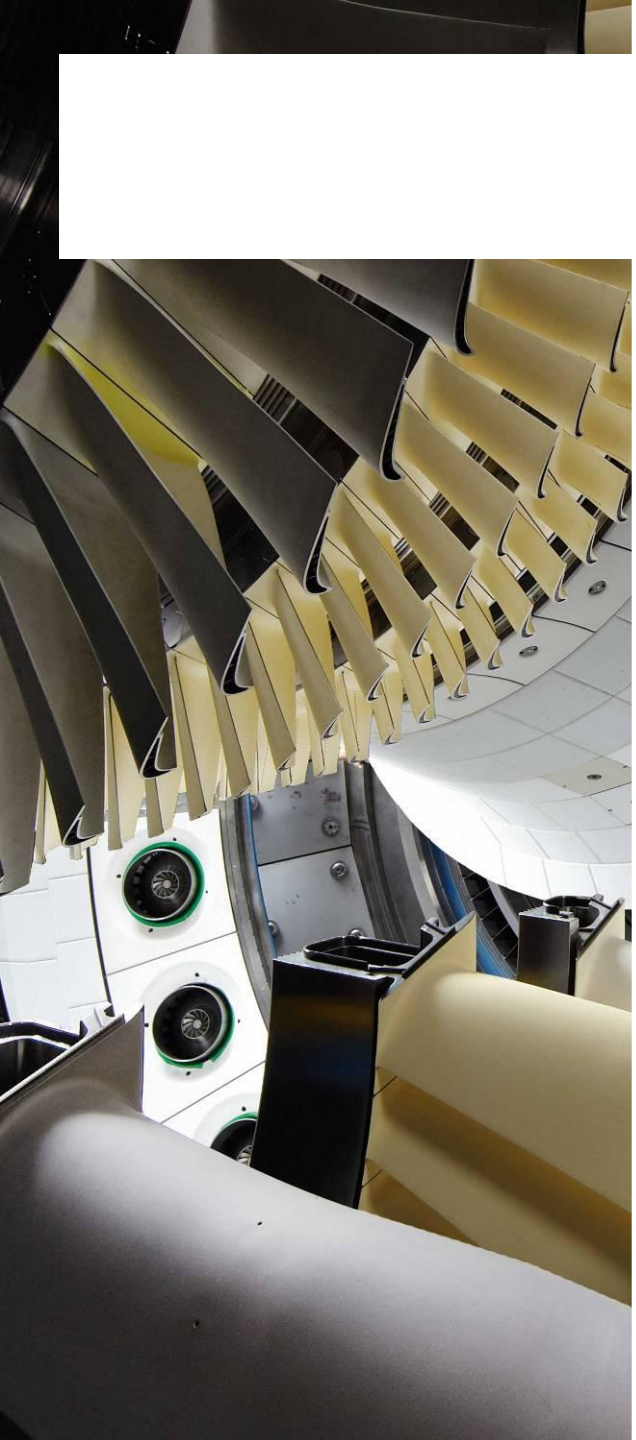
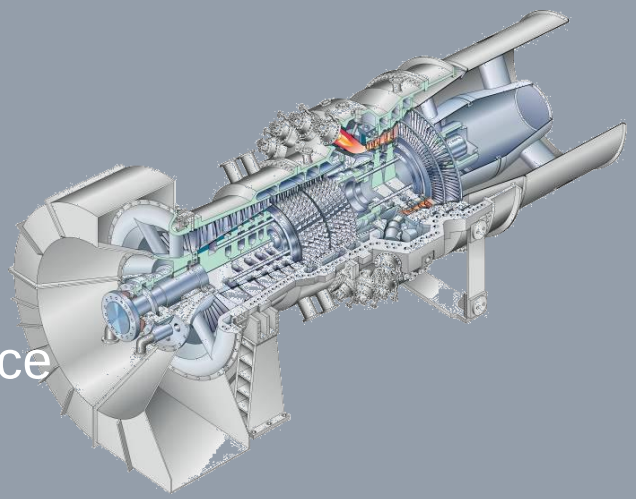


SIEMENS

H2 Turbine Development for IGCC with CCS: Project Overviews and Technical Issues

Susan Scofield
Siemens Energy, Inc.



2011 UTSR Conference
Ohio State University
October 25, 2011

Acknowledgements

- This material is based upon work supported by the US Department of Energy, under Award Number DE-FC26-ONT42644.

- The Siemens team wishes to thank Mr. Robin Ames, NETL Project Manager and Mr. Rich Dennis, NETL Turbine Technology Manager for the opportunity to collaborate on the development of these novel technologies for the Advanced Hydrogen Turbine.

Agenda

SIEMENS

Hydrogen Turbine Program Goals

Technology Areas / Advancements
- **Combustion**
- **Turbine**
- **Materials**

Siemens - DOE – UTSR Partnership

Agenda

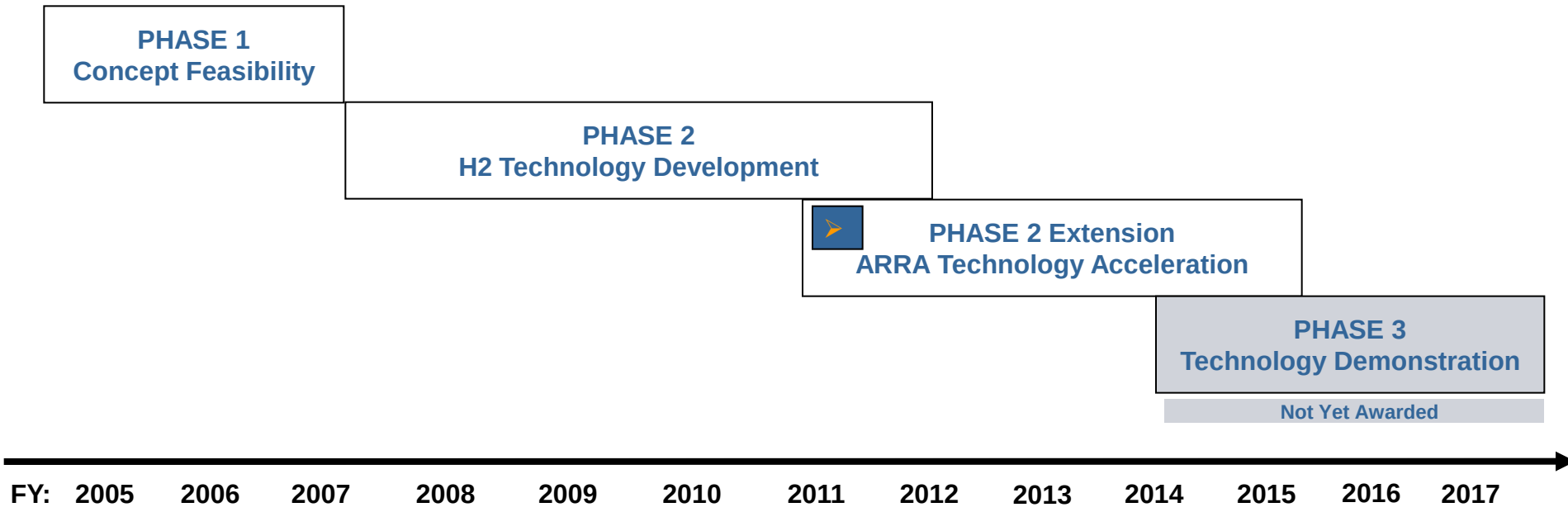
SIEMENS

- Hydrogen Turbine Program Goals
- Technology Areas / Advancements
  - Combustion
  - Turbine
  - Materials
- Siemens - DOE – UTSR Partnership

DOE - Siemens
Advanced Hydrogen Turbine Program Strategic Goal

SIEMENS

Siemens was contracted for PHASE 1 and PHASE 2 of a multi-year program to develop an advanced GT for Hydrogen / Syngas applications.



- **3-5% pt. improvement in CC efficiency over baseline**
- **H_2 Turbine with 2 ppm NOx**
- **20 – 30% ($/kW) Cost Reduction in Power Plant**

IGCC Market Challenges

SIEMENS

- IGCC plant capital and O&M costs

20 Oct: Duke Energy expects that the Edwardsport IGCC plant cost = $2.98 billion, 618MW (Previous estimate $2.72 billion)

- Improved IGCC plant performance and plant availability

Efficient GT
Overall Cycle Efficiency

- Minimizing the impact of CO_2 capture

CO2 Sequestration, Plant Efficiency

- Legislative and regulatory uncertainty related to CO2

H.R. 2454: American Clean Energy and Security Act of 2009

Demonstrating that IGCC technology is a viable coal based power generation option brings significant R&D Challenges

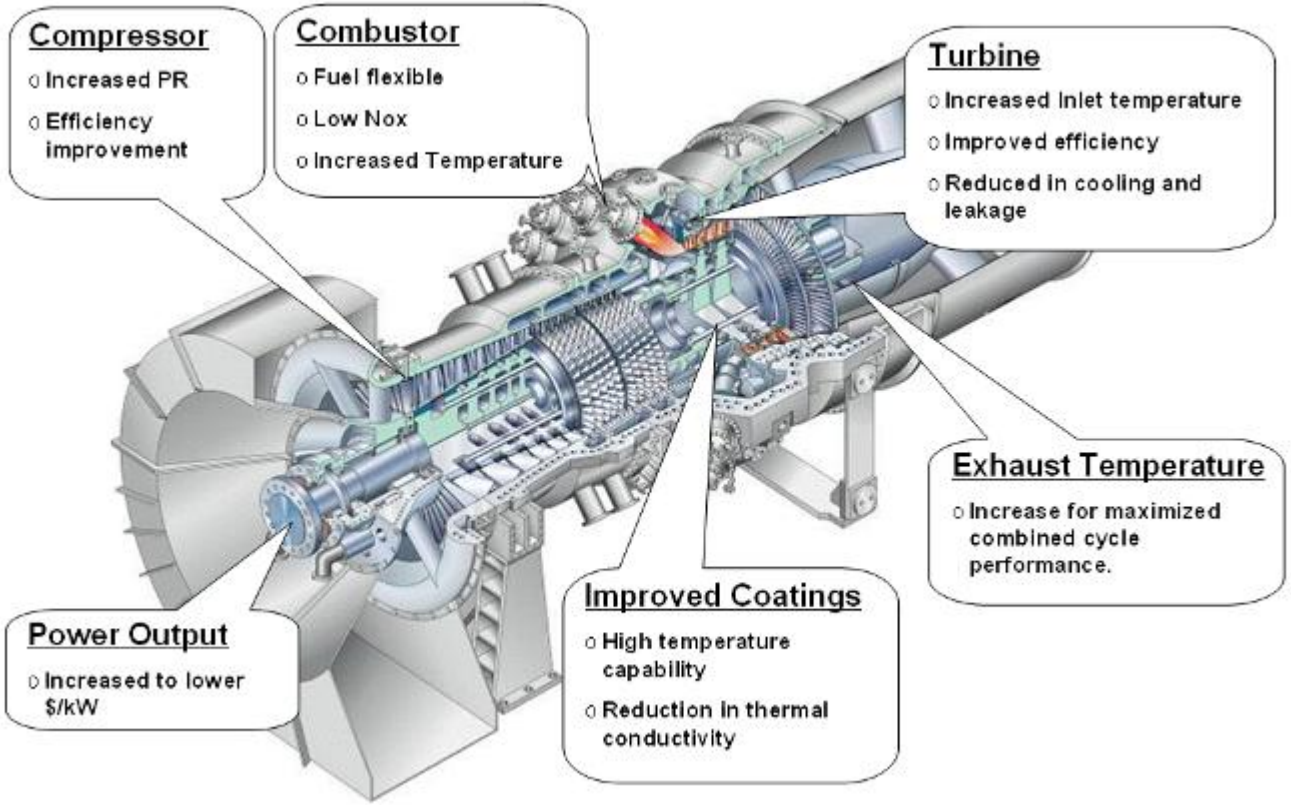
Hydrogen Turbine Program Development Activities

SIEMENS

IGCC Plant

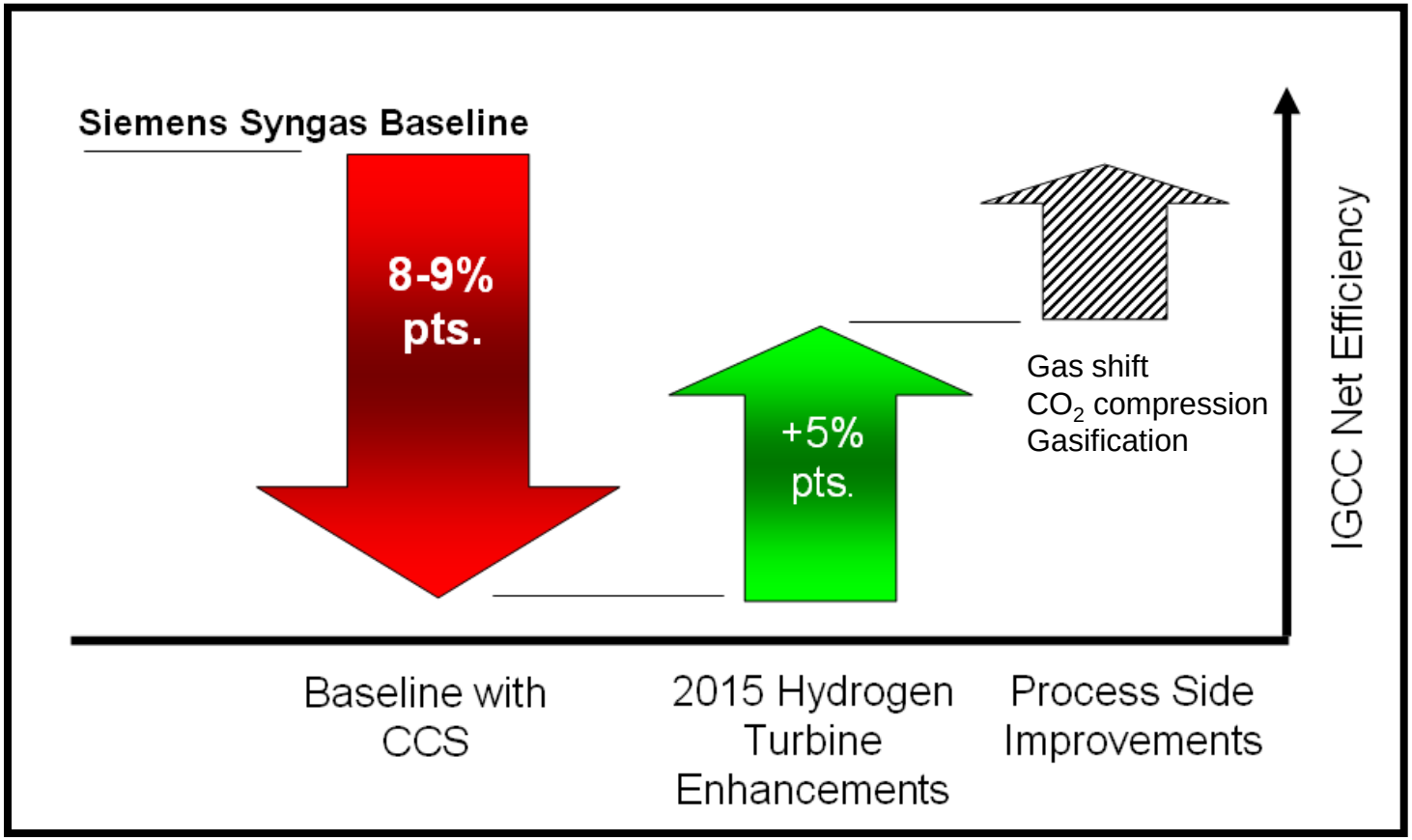
- Improved Efficiency
- Fuel Flexibility
  NG,Syngas,H_2
- Low Emissions
- Reduction in Plant Cost $/KW
- CO_2 Sequestration Ready

Targeted Areas of R&D



Program Development and Major Activities Driven by Plant Level Goals

Carbon Capture and Sequestration Impacts Plant Cycle



Hydrogen turbine Program technology advancements power block efficiency : Recover ≥50% of the CCS penalty

Agenda

SIEMENS

Hydrogen Turbine Program Goals

Technology Areas / Advancements
- **Combustion**
- **Turbine**
- **Materials**

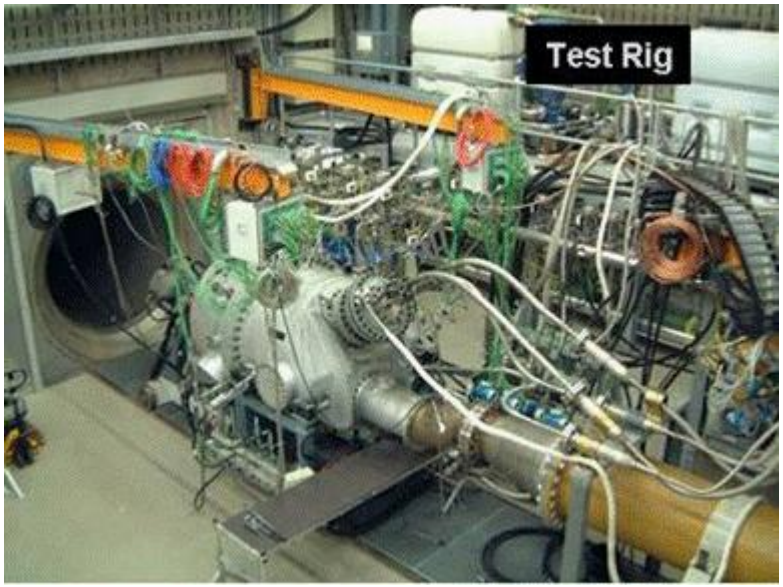
Siemens - DOE – UTSR Partnership

Combustion Systems
Challenges and Areas for R&D

SIEMENS

Premix Combustor

- Flame Speed
- Flashback
- Combustion Dynamics / Acoustics
- Fuel Flexibility (Always need back-up fuel)
- Low Emissions at Increased Temperature
- Potential for Large variation in fuel properties depending on feedstock.



Benefits: Premix Combustor allows for Higher Firing Temperature and Lower Dilution

Combustion System Options for IGCC Applications

SIEMENS

Current Offering

Diffusion Flame Combustion

- <15 ppm NOx achievable at high firing temperature
- Requires dilution for NOx
- 25 ppm NOx emissions with dilution on natural gas

Development Target

Premix Combustion System

- Demonstrated rig testing at high temperature without N_2 dilution.
- Gains on flashback/dynamics reduction.
- Proven single digit NOx emissions with natural gas.

Advanced Premix Combustor: Additional R&D in Progress

Agenda

SIEMENS

Hydrogen Turbine Program Goals

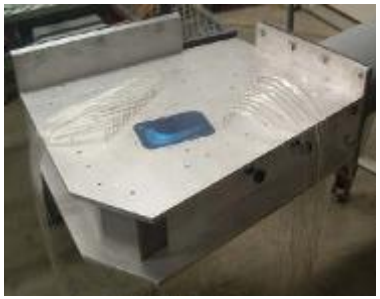
Technology Areas / Advancements

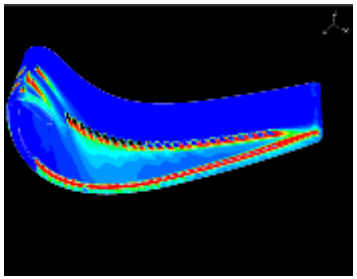
- Combustion
- Turbine
- Materials

Siemens - DOE – UTSR Partnership

Turbine Systems
Challenges and Areas for R&D

SIEMENS





Improved Aerodynamic and Heat Transfer Predictions

Advanced 3D CFD Modeling

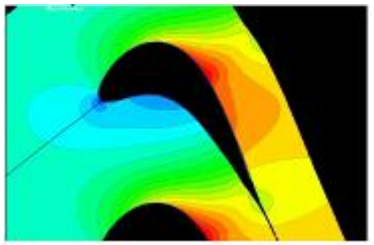
Manufacturing of Novel Component Concepts

Rapid Design Iterations

Rapid Prototyping

Sealing Technology

Turbine Material Advancements



Benefits: Opportunity for Significant Efficiency Gain

Turbine Development Options
For IGCC Manufacturing Applications

SIEMENS

SIEMENS

MIKRO
BREAKTHROUGH TECHNOLOGIES

Siemens Energy, Inc. **Mikro Systems, Inc.**

COMMUNICATION: United States Department of Energy

DATE: 28 June, 2011

RE: Technology license agreement between Mikro Systems, Inc. and Siemens Energy, Inc.

Siemens Energy Inc. and Mikro Systems Inc. are pleased to announce a new collaborative technology license agreement with the objective to continue the R&D progression of gas turbine technology improvements between U.S. DOE SBIR program award recipient Mikro Systems and OEM Siemens Energy.

Continuing the legacy of high-tech R&D and Manufacturing Methods

http://www.fe.doe.gov/news/techlines/2011/11044-Research_Grant_Leads_to_Gas_Turbin.html

Agenda

SIEMENS

Hydrogen Turbine Program Goals

Technology Areas / Advancements

- Combustion
- Turbine
- Materials

Siemens - DOE – UTSR Partnership

Materials & Coatings Systems Challenges and Areas for R&D

SIEMENS

Challenges:

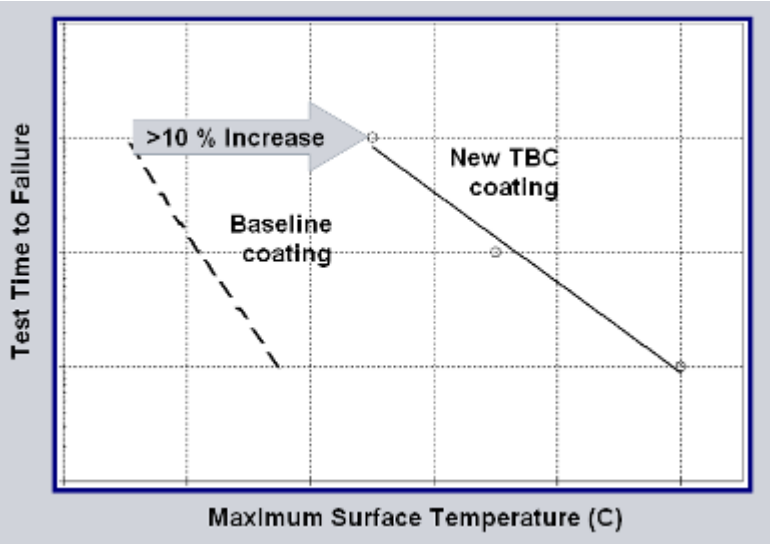
- **Advancement of High Temperature TBC for Low Thermal Conductivity**
- **Environmental Issues with Syngas & High Hydrogen Fuels**
- **Corrosion & Oxidation Capability of Syngas & High Hydrogen Fuels**

Baseline	Experiments	Validation
• Leveraging IGCC and NGCC Experience	• Literature Search • Initial Hypotheses • Design of Experiments • Target Setting	• Target Demonstration • Design data generated • Design tools updated • Environmental Testing

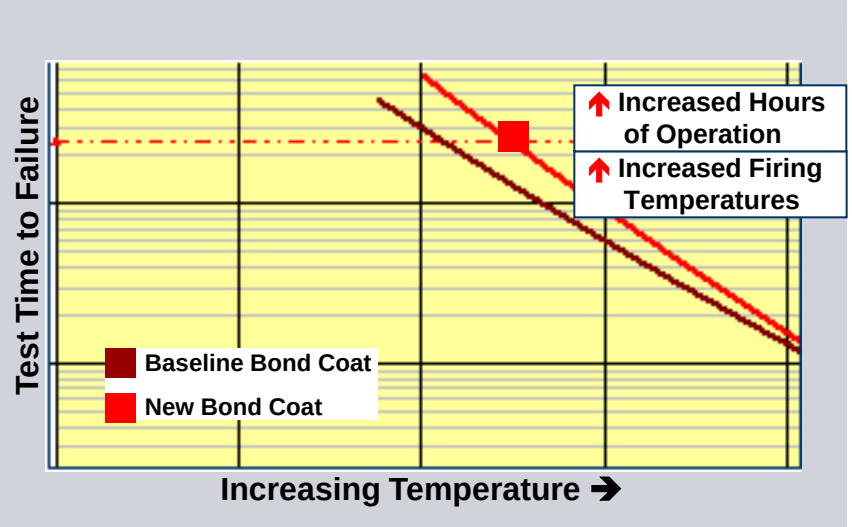
Advanced materials and coatings are critical to the success of H2 Turbine components and systems development.

Materials Systems Status
For Advanced Design Applications

SIEMENS



Enables higher firing temperatures



Improved oxidation.
Longer life until TBC spallation

TBC:
- Surface temperature initial trials complete:
  - Initial validation shows increase in surface temperature compared to the baseline

Bond Coat:
- Concept down-selection completion criteria:
  - Oxidation
  - Mechanical integrity
  - Spallation properties

Next Step: Prototype Manufacturing and Validation Phase

Agenda

SIEMENS

Hydrogen Turbine Program Goals

Technology Areas / Advancements
- **Combustion**
- **Turbine**
- **Materials**

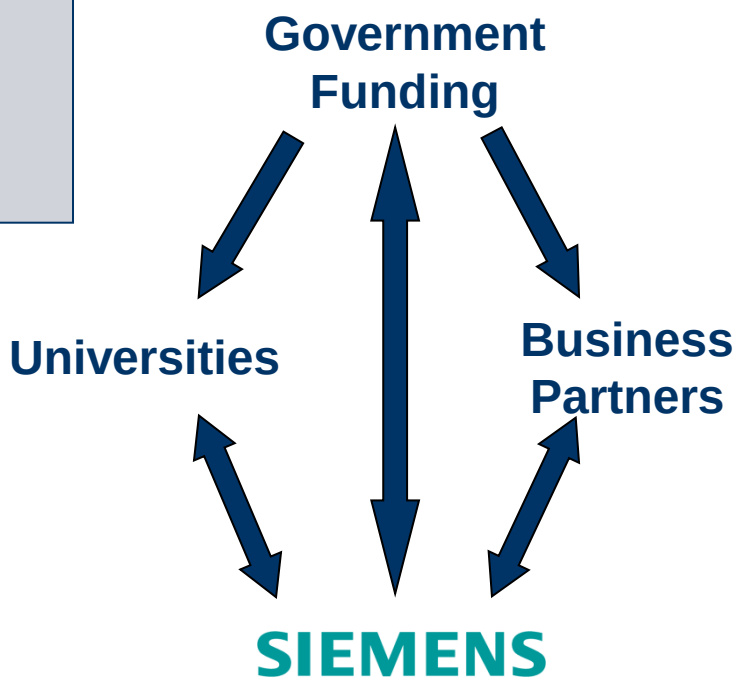
Siemens - DOE – UTSR Partnership

Technology Collaboration: Leveraging Relationships in World-Wide R&D Network

SIEMENS

Market Trends:

- Emissions ↓
- Efficiency ↑
- Life Cycle Cost ↓



Energy Policy:

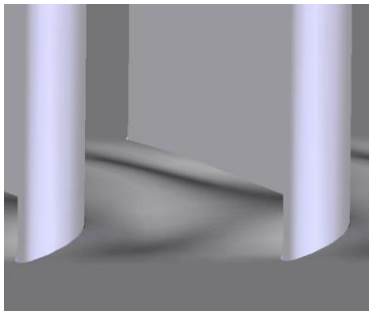
- Global Warming ↓
- Create New Jobs ↑
- Energy Independence ↑

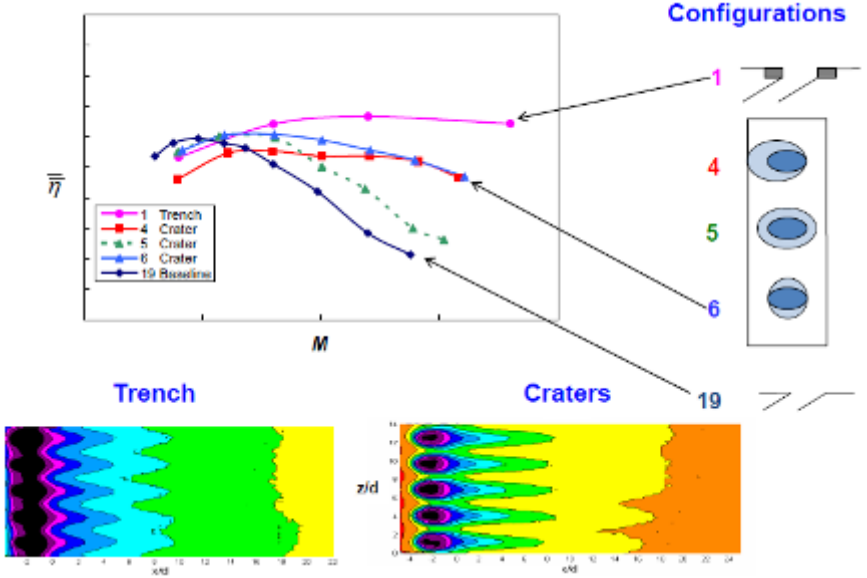
Significant Benefit:

- **Siemens is a part of a broad and collaborative Research & Development, Product Manufacturing and Validation Network.**
- **Common Goal: Accelerate emerging technologies for thermodynamic and environmental performance in Turbo Machinery.**

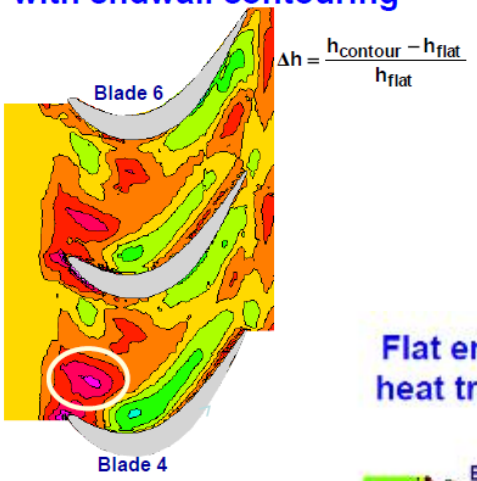
Siemens – UTSR Partnership: UT-Austin and Penn State

SIEMENS

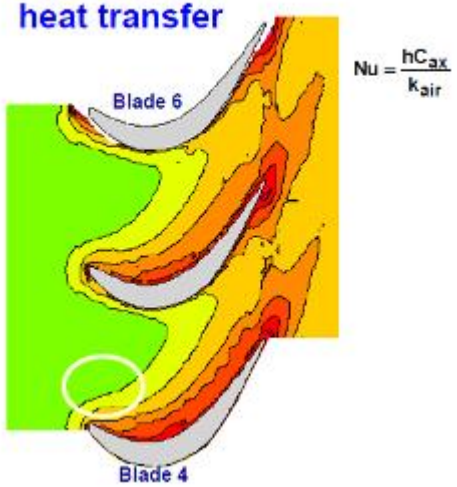




Heat transfer augmentation with endwall contouring



Flat endwall heat transfer

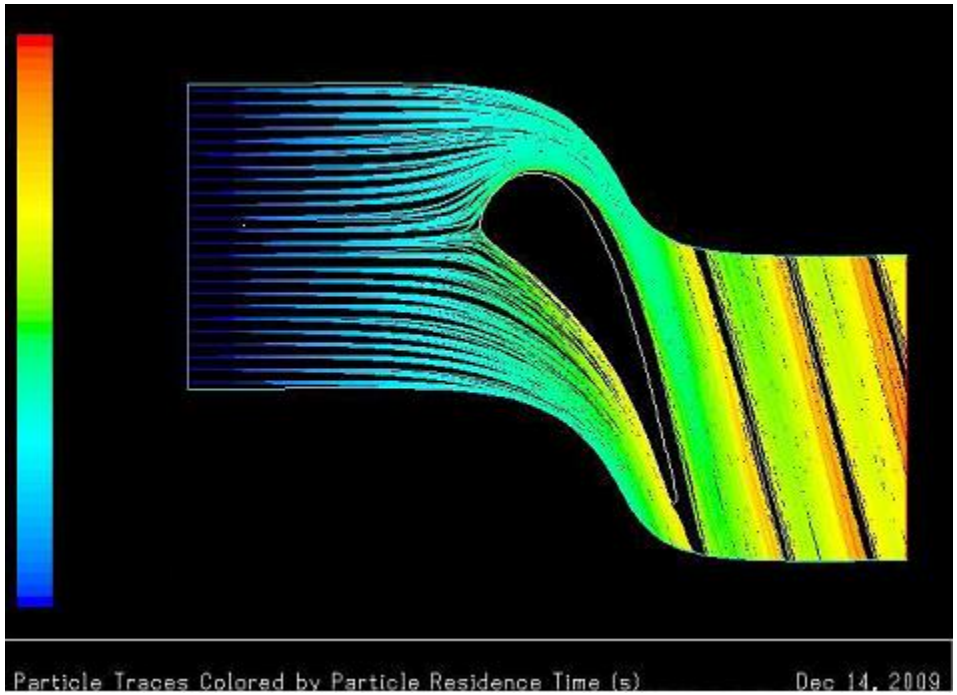


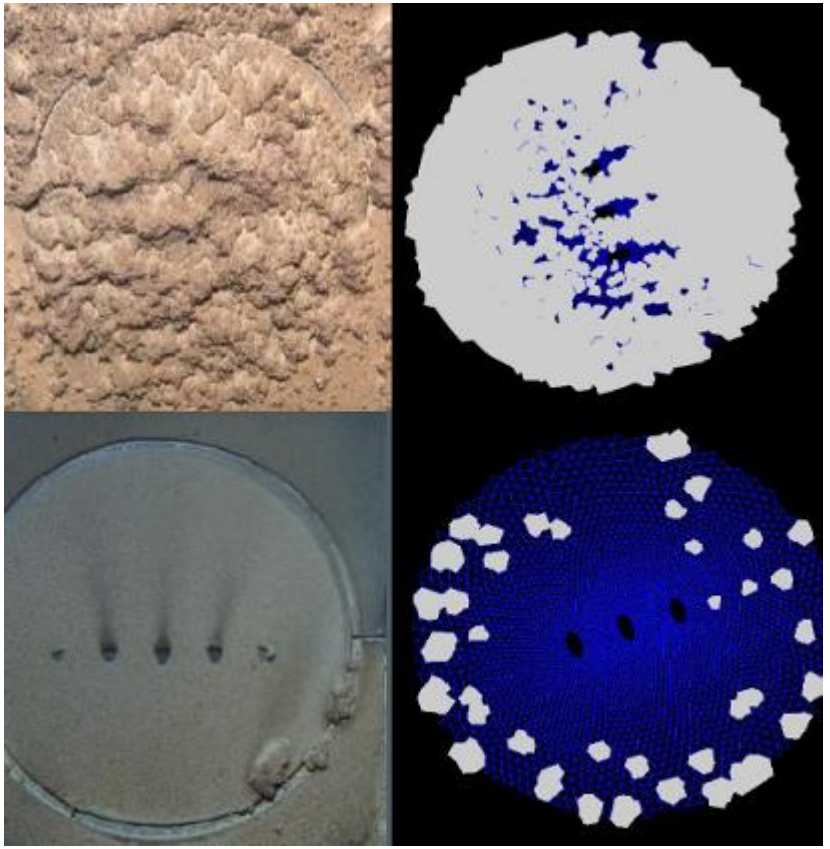
Improving Turbine Components Durability

Trenched Film Cooling, Contoured End Walls

Siemens – UTSR Partnership: University of North Dakota and Ohio State

SIEMENS



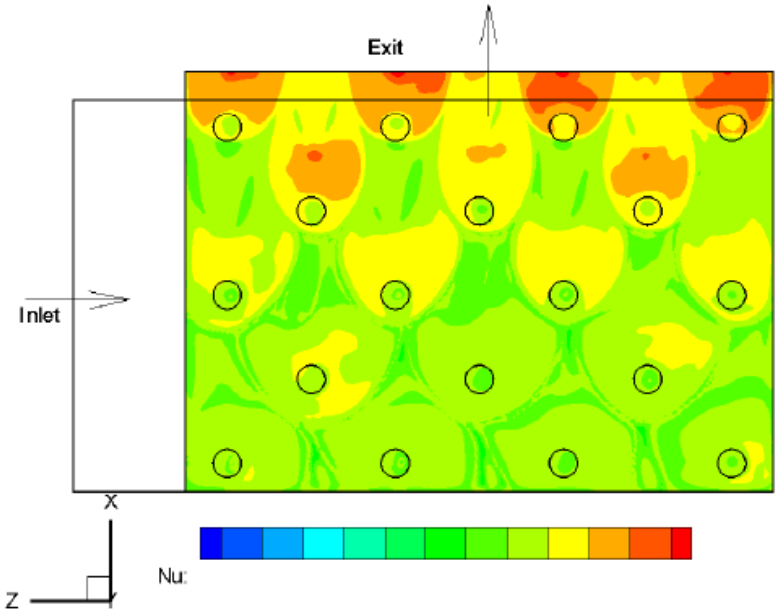


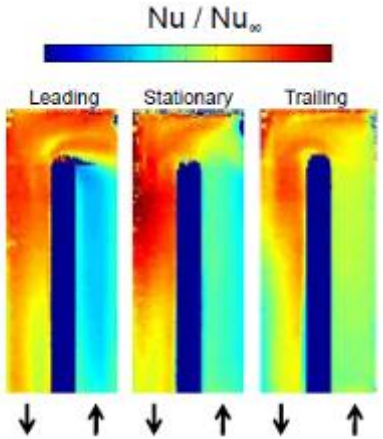
Cooling Strategies for Vane Leading Edges in a Syngas Environment

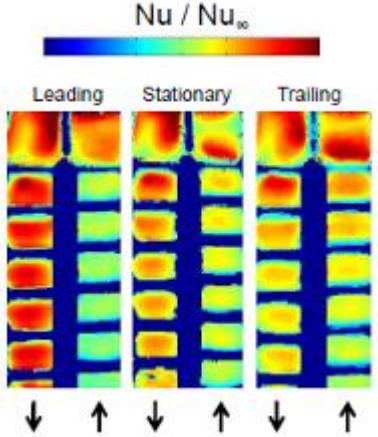
Including Effects of Deposition and Turbulence

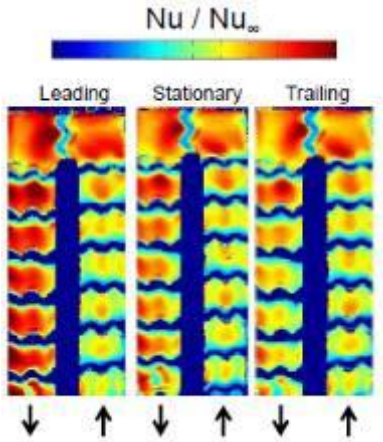
Siemens – UTSR Partnership: Virginia Tech

SIEMENS







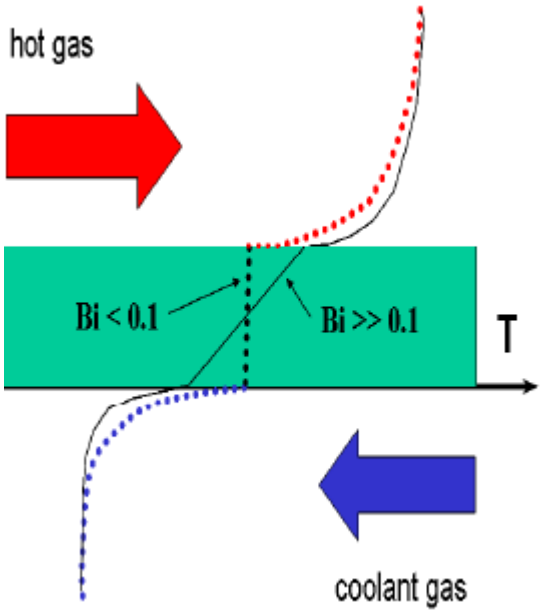


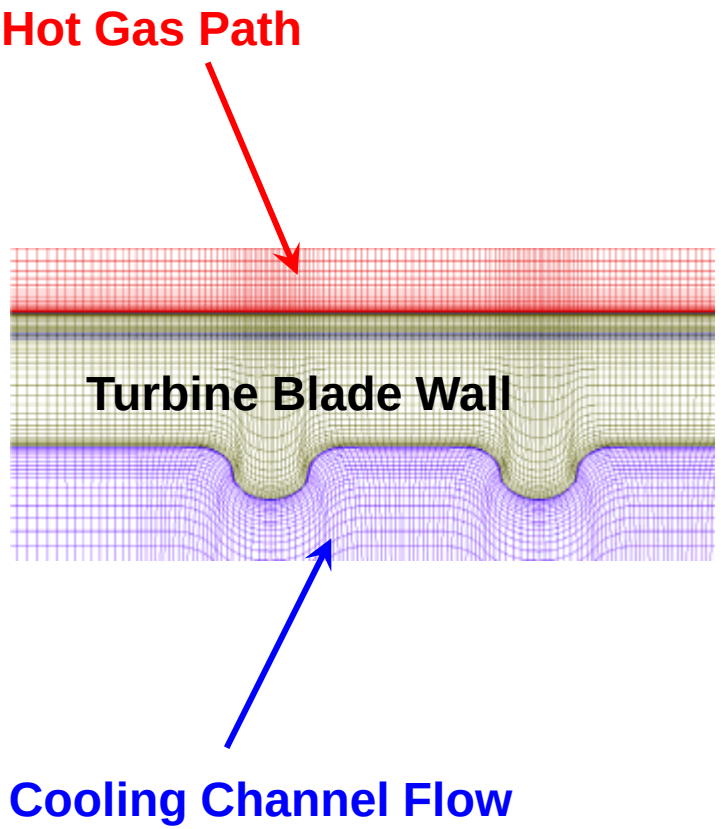
Heat Transfer Effects from Advanced Internal Cooling Geometries

Double Wall Schemes With and Without Effect of Rotation

Siemens – UTSR Partnership: Purdue

SIEMENS



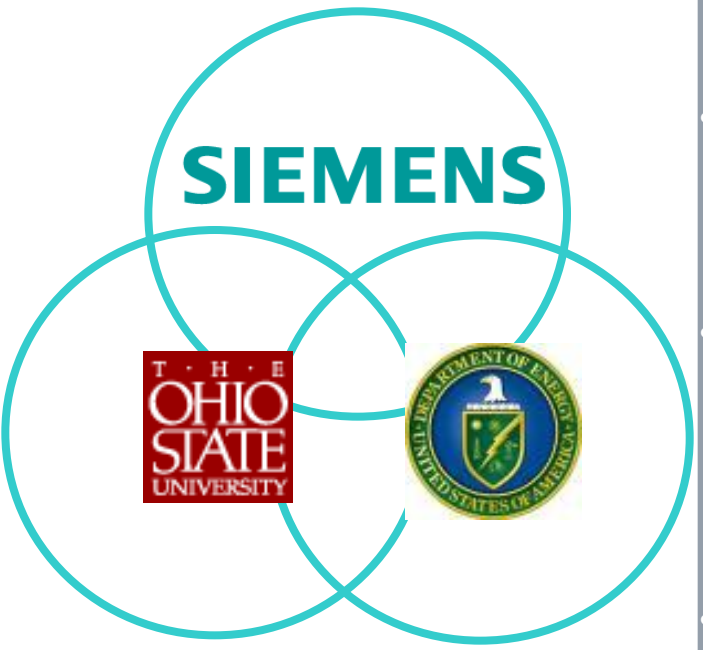


Turbine-Cooling Design and Analysis

The Role of Biot Number

Siemens - DOE - Universities
The Leverage of Mutual Partnership: Estimated by 2015

SIEMENS



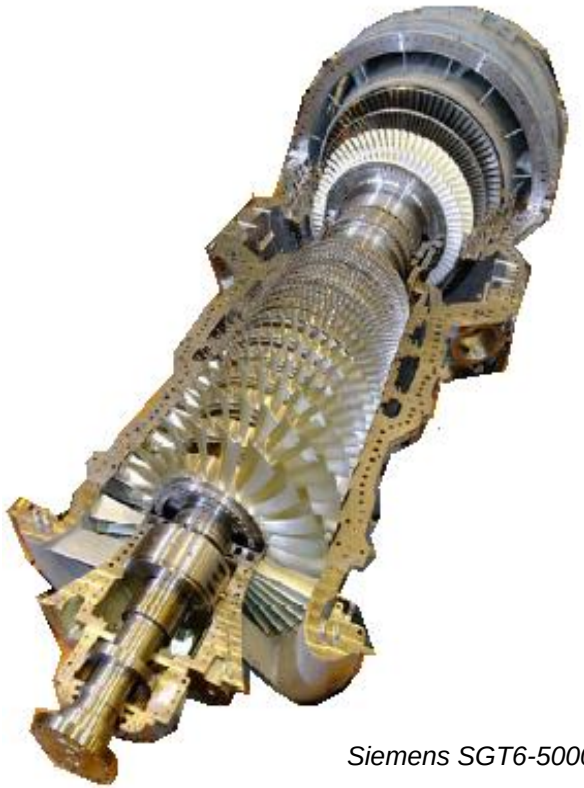
- Innovations in Gas Turbine Technologies for increasing Combined Cycle Power Plant Efficiencies and Performance
- Reduction of ~12,000 tons of CO_2 emissions per year by each Next Generation Siemens Gas Turbine
- Partnering with 25 top U.S. universities for R&D in the field of Turbo- machinery
  - → over 75 graduate students
- Over 150 Invention Disclosures submitted to USPTO
- Establishing an “engineering talent pipe-line” for our future
- Job creation / economic development of local U.S. economy

Summary:
Ensuring Commercial Viability of the Hydrogen Turbine

SIEMENS

Siemens advanced GT technology aligns with future industry drivers

- Carbon capture and sequestration ready
- Improving gas turbine and combined cycle **efficiency**
- Providing **near term** technology infusion into current engines
- Lowering **$/kW** cost with increased output and efficiency
- Significantly reducing **CO_2** and **NO_x** emissions
- Enabling greater reliance on domestic resources



Siemens SGT6-5000F

U.S. – 70,000 Employees
Siemens Investing in the Future

SIEMENS

Siemens Diverse Energy Product Portfolio

Wind, Solar, Gas Turbines, Clean Coal

Supporting US and Global policy for clean energy / energy efficiency

Siemens is Hiring in US

Thinking Globally, Acting Locally

Green Jobs

- Nacelle manufacturing facility for wind power - Hutchinson Kansas
- New N. American Hub for GT Manufacturing - Charlotte, North Carolina
- New Amtrak contract (medium-size light rails)
  - Manufacturing facility developed - Sacramento, California

Infrastructure Investment ~ $.5 Billion; Hired 3,000 people (last 2 – 3 years)

http://www.usa.siemens.com/en/jobs_careers/us_jobs.htm

Thank You